REPORT DOCUMENTATION PAGE

Form Approved OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 1997	

4. TITLE AND SUBTITLE
Development of an Integrated Mobile Meteorological Monitoring System for Use in Open Burning and Open Detonation Activities

5. FUNDING NUMBERS
N/A

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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Boulder, CO

Atmospheric Sciences Modeling Division
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US Environmental Protection Agency
Research Triangle Park, NC

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

SERDP
901 North Stuart St. Suite 303
Arlington, VA 22203

American Meteorological Society

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
N/A

11. SUPPLEMENTARY NOTES
First Symposium on Integrated Observing Systems, American Meteorological Society, February 2-7, 1997, Long Beach, California.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release: distribution is unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT ***(Maximum 200 Words)***

19990521 149

14. SUBJECT TERMS
open burning
open detonation
meteorological monitoring
SERDP
SERDP Collection

15. NUMBER OF PAGES
6

16. PRICE CODE N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclass.	unclass.	unclass.	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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pp 145-149

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1. INTRODUCTION

During the Cold War the United States military accumulated a vast arsenal of warfare materials. These included explosive munitions, propellants, and various pyrotechnic materials. Now that the Cold War has ended, the U. S. is faced with the task of disposing these energetic materials in an environmentally safe manner. Disposal of the demilitarized stockpile will be a momentous undertaking. The current surplus inventory is estimated to be at 450,000 tons and growing rapidly at a rate of 40,000 tons per year (U. S. Army 1995). These materials are distributed throughout the country at several hundred Department of Defense (DOD) and Department of Energy (DOE) installations. Many of the materials are old, unstable, and unsafe.

The most common disposal method currently in use is open burning (OB) and open detonation (OD). OB/OD activities are a relatively simple and cost effective means for stockpile reduction. However, these activities can generate air pollutants such as SO_2, NO_x, CO, particulates, metals, cyanides, and volatile and semivolatile organic compounds. Any facility which intends to use OB/OD disposal methods must meet permit requirements under Part 264, Subpart X of the Resource Conservation and Recovery Act (U. S. EPA 1993). To obtain a Subpart X permit, a facility must provide information on the materials being destroyed, the type and quantity of pollutants being released, a description of how these pollutants will be dispersed in time and space, and an assessment on the potential impact on human health and the surrounding ecosystem by these emissions both on a short-term and long-term basis. A Subpart X permit is issued by an Environmental Protection Agency (EPA) Regional Office only if the facility can demonstrate that the impact from OB/OD activities poses no significant threat to human health and the surrounding ecosystem. Very few Subpart X permits have been granted. This is due, in part, to the lack of an EPA approved model specifically designed to simulate OB/OD transport and dispersion. In many instances, the facility applying for a permit does not have enough data to demonstrate compliance. The few permits which have been granted are very restrictive in scope.

The Strategic Environmental Research and Development Program (SERDP) has funded EPA's National Exposure Research Laboratory (NERL) and the National Oceanic and Atmospheric Administration's (NOAA) Environmental Technology Laboratory (ETL) to develop an OB/OD air pollution dispersion model and a mobile meteorological observing platform which will be used to acquire the necessary information needed for obtaining a Subpart X permit. Weil et al. (1995, 1996a, 1996b) are currently undertaking the development of a Gaussian puff model which considers source emissions, plume rise, transport and dispersion from either an OB or OD. The mobile meteorological monitoring system will be used to provide a detailed characterization of the structure and dispersive state of the atmospheric boundary layer (ABL). In addition, those data acquired by the mobile monitoring system will be used by the model for predicting transport and dispersion of emissions released by an OB or OD into the atmosphere. This paper describes the integrated suite of meteorological sensors.

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2. SENSOR DESCRIPTION

Because the plumes released from OB/OD activities rise quickly, it is important to accurately characterize the state of the ABL. In order to accomplish this, a suite of ground-based *in situ* and remote sensors will be used to characterize the vertical structure of the atmosphere from the surface up to 2 to 3 km. The original design specifications for a measurement system were first presented at an OB/OD workshop in February 1995 (Banta 1996). A consensus was reached on the measurements needed to characterize the ABL and for input into the OB/OD dispersion model. The integrated system was designed to be mobile so that the system could be easily moved from one OB/OD site to another with a minimal amount of time and effort.

Tower-based *in situ* sensors will be used to acquire surface layer measurements while a suite of remote sensors, mounted on a flatbed trailer, will be used to obtain vertical profile data. The accompanying electronics and data acquisition systems will be located in a nearby enclosed mobile trailer.

2.1 *In Situ Sensors*

A 20-m open-lattice aluminum tower will serve as a measurement platform for a number of *in situ* sensors. An R. M. Young wind monitor (05701-AQ) will measure scalar-averaged wind speed (S), vector-averaged wind speed (U), vector-averaged wind direction (θ), and the standard deviation of the wind direction (σ_θ) at 10 m. A Vaisala HMP-35A probe will be used to measure air temperature (T) and relative humidity (RH) at 2 m. Net radiation (Q_N) will be acquired with a Radiation Energy Balance Systems net radiometer. A Vaisala PTB-101B will be used for measuring barometric pressure (P) while precipitation (R) data will be acquired by a Texas Electronics tipping bucket rain gauge. A Campbell Scientific CR-10 data logger will be used to interrogate these sensors and log their data as 15-min values. These data will be telemetered via a radio frequency (RF) line-of-site link to the "hub" computer on regularly scheduled basis (typically once per hour) or on demand.

Two Metek sonic anemometers (USA-1) will be mounted on the tower at 5 and 20 m. These fast response instruments will acquire 15-min mean (u, v, w, T_v) and standard deviation (σ_u, σ_v, σ_w, σ_{Tv}) of the three-component wind velocity and virtual air temperature. Using eddy correlation techniques, these sonics can also determine turbulence parameters such as the kinematic heat flux ($w'T_v'$), kinematic momentum flux ($u'w'$), friction velocity (u_*), temperature scale (T_*), the Monin-Obukhov length (L), drag coefficient (C_D), and the longitudinal (I_x), lateral (I_y), and vertical (I_z) turbulence intensities. Each sonic transmits its data by an RS-232 serial line to a computer.

The monitoring system is designed to incorporate a number of ancillary tower systems where complex terrain settings demanded a better representation of the surface layer wind field. Should this need arise, a sufficient number of 10-m towers will be deployed. In this case, each tower will be equipped only with an R. M. Young wind monitor and a Vaisala air temperature and relative humidity probe. A Campbell Scientific CR-10 data logger will be used to acquire these data and the same RF telemetry link will be utilized for transmission of this information to the hub computer. A summary of the surface layer *in situ* instruments and measurements is given in Table 1.

TABLE 1. Summary of surface layer *in situ* sensor measurements.

Manufacturer	Model	Measurement
R. M. Young	05701-AQ	S, U, θ, σ_θ
Vaisala	HMP-35A	T, RH
REBS	net radiometer	Q_N
Vaisala	PTB-101B	P
Texas Elect.	tipping bucket	R
Metek	USA-1	u, v, w, T_v σ_u, σ_v, σ_w, σ_{Tv} $w'T_v'$, $u'w'$, u_*, T_*, L, C_D, I_x, I_y, I_z

2.2 *Remote Sensors*

Two types of profilers will be used to acquire detailed wind field data. The first is a Radian 924 MHz phased-array Doppler wind profiling radar (LAP-3000). The range of the radar is approximately 2 to 4 km with a resolution of 100 m. The remotely-sensed measurements include horizontal wind speed (U) and direction (θ), the standard deviation of the horizontal wind direction (σ_θ), and vertical wind speed (W). In addition, the radar estimates the refractive index structure parameter (C_N^2). This value is a direct measurement of the turbulent intensity of humidity fluctuations in the ABL and is useful for estimating the mixed layer height (z_i).

The second profiler is a Radian phased-array Doppler sodar (600PA). This sensor will be used to acquire wind profiles in the first several hundred meters of the planetary boundary layer. The sodar range is approximately 500 m with a resolution of 25 m. The sodar acquires the same wind field data (U, θ, σ_θ, W) as well as the standard deviation of the vertical wind speed (σ_w). The backscatter information acquired by the sodar is directly related to the temperature structure function (C_T^2). This measurement is useful in depicting inversion layers and other regions were temperature gradients exist.

A radio acoustic sounding system (RASS) has been included by combining the radar and sodar to acquire profiles of virtual air temperature (T_v). The range of the RASS is 1 to 1.5 km with a resolution of 100 m. This RASS differs from the more traditional systems used in the past which utilized four separate acoustic sources surrounding the radar. In this configuration, the sodar is now the acoustic source. The phased-array design allows the acoustic beam to be steered upwind which optimizes data capture efficiency. During the first 25 min of a 30-min sampling interval, the radar and sodar operate independently from each other acquiring wind profile and backscatter data. During the last 5 min, the RASS mode is initiated. The sodar and radar work together to determine a mean profile of T_v.

A Vaisala CT25K ceilometer will be used to estimate the aerosol backscatter profile (I_λ) and cloud base height (z_b) from the surface to ~ 4 km with a 15-m resolution.

The radar, sodar, and ceilometer are mounted on a 7-m flatbed trailer. The radar sits on the front end of the trailer with the sodar in the rear. The ceilometer resides near the back edge of the trailer (Figure 1). Leveling of the trailer and sensors is accomplished with seven jacks mounted along the sides and front of the trailer.

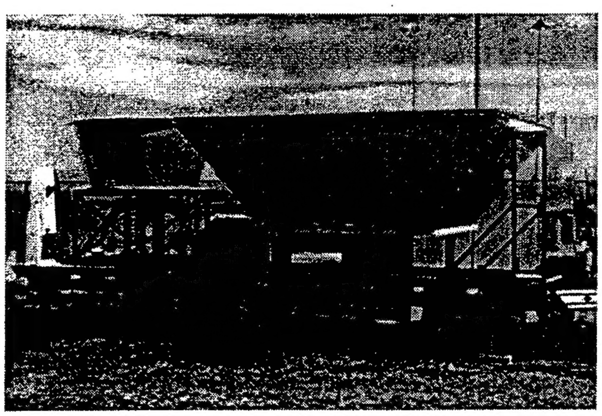

Figure 1. Remote sensors mounted on flatbed trailer. From left to right: Ceilometer, sodar, and radar.

Assembly and evaluation of this integrated mobile meteorological monitoring system has been conducted at the Boulder Atmospheric Observatory (BAO) in Erie, Colorado (Kaimal and Gaynor 1983). Meteorological measurements taken from the BAO 300-m tower have been used to establish the reliability of the upper-air data obtained by the remote sensors. A summary of the upper-air remote sensing instruments and measurements is given in Table 2.

3. COMPUTER SYSTEMS

A substantial number of computer systems and accompanying electronics are needed for data acquisition and processing. The mobile system is designed to be modular and integrated. Thus, all of the electronics are sheltered in an enclosed trailer. The heated and cooled trailer is 2.4 m wide and 5.5 m long. The procurement of a large trailer was necessary in the event more electronics were needed for additional meteorological sensors.

Figure 2 is a depiction of the integrated measurement system. The radar and sodar are each operated by their own 486 personal computer (PC). An RS-232 serial line between the radar and sodar computer enables these two systems to communicate in the RASS data acquisition mode. A third 486 PC is dedicated to obtaining data from the ceilometer and two sonic anemometers using RS-232 serial lines. These three computers are networked into a "hub" computer using NodeRunner 2000/C self-describing Internet cards with LANtastic 6.0 network software. All tower-based measurements are relayed through a RF link which is hooked directly into the hub computer. A fifth computer is linked to the hub using the same type of network connection. This computer is dedicated to the OB/OD dispersion model developed by Weil et al. (1995, 1996a, 1996b). Remote access into the hub computer is possible via telephone line and a high speed modem. Data from the hub computer can also be downloaded by File Transfer Protocol (FTP) through an Internet connection.

The hub computer employs a clock card to keep an accurate time. The hub periodically checks the four other computers and resets their respective clocks should they differ by more than 5 s. All of the computers and electronics require standard 110/120 AC, 60 Hz voltage. These systems are protected against power surges and outages with an uninterruptable power supply. The hub computer receives and records all meteorological data from each computer. These data are recorded on an internal hard disk and on a 1.3 Gbyte optical disk. The optical disk acts both as a backup mechanism as well as enabling dissemination of large volumes of information.

TABLE 2. Summary of upper-air remote sensor measurements.

Manufacturer	Model	Variables	Minimum/Maximum Range (m)		Resolution (m)
Radian	LAP-3000	U, θ, W, σ_θ, C_N^2	125	~ 2500	100
Radian	600PA	U, θ, W, σ_θ, σ_w, C_T^2	50	~ 500	25
Radian	RASS	T_v	125	~ 1500	100
Vaisala	CT25K	I_λ, z_b	30	~ 4000	15

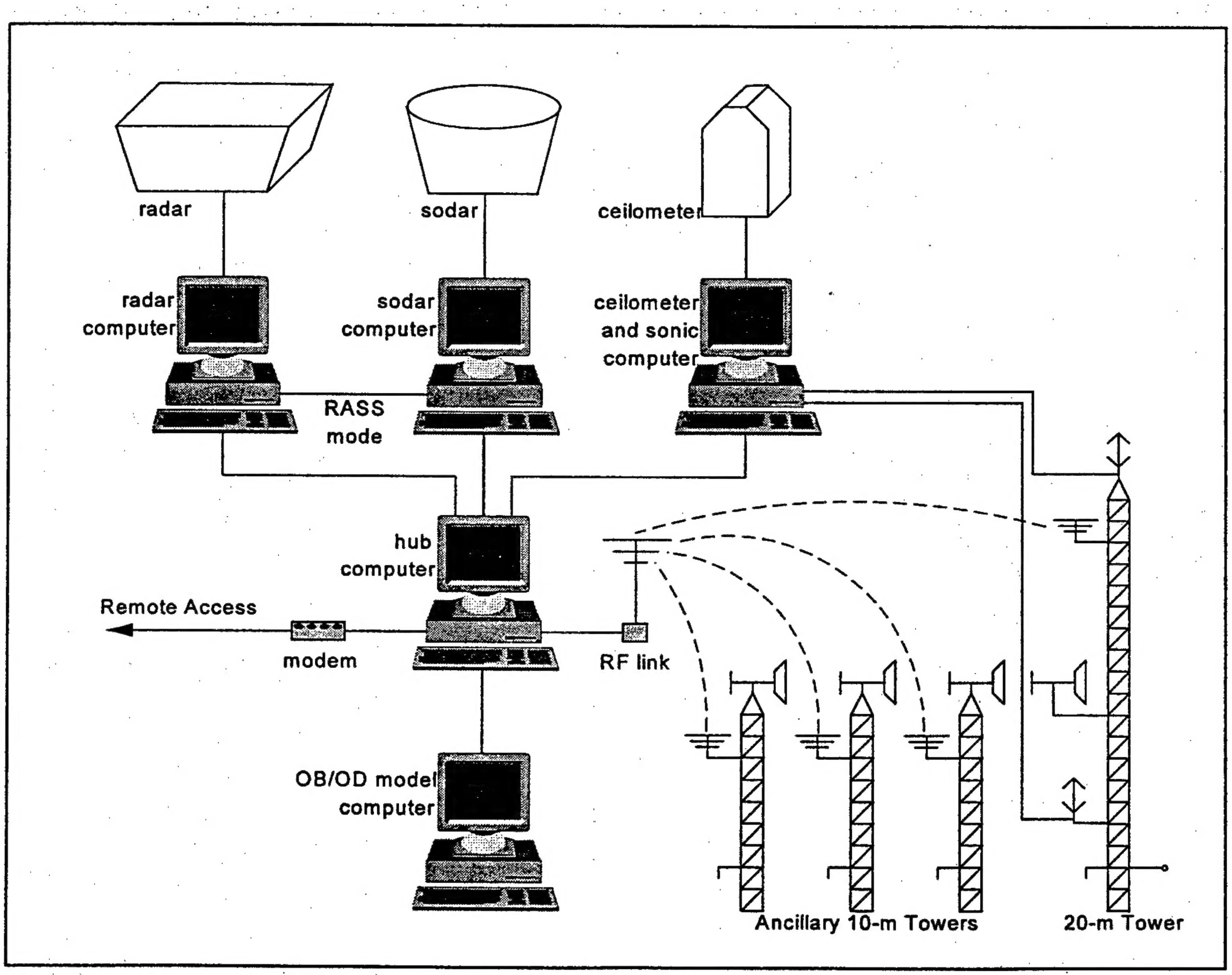

Figure 2. Schematic of mobile meteorological monitoring system.

The hub computer also processes some of these incoming data. A real-time QA/QC editor (Weber and al. 1993) is employed to check for the quality and consistency of the radar wind profiler data. Newly developed mixed layer height determination algorithms (White 1993; Angevine et al. 1994) have also been incorporated which estimate z_i using data acquired by the radar, sodar, ceilometer and sonic anemometers. The hub computer also contain algorithms which will process the data in a format needed by the OB/OD model for real-time forecasts of transport and dispersion of released pollutants.

4. SUMMARY

An integrated mobile meteorological monitoring system has been designed and constructed to characterize the atmospheric boundary layer at facilities which conduct open burning and open detonation of surplus military munitions. Because the plume released from an OB/OD can rise quickly, it is important to accurately predict how the atmosphere will disperse the plume. In order to accomplish this, an integrated suite of ground-based *in situ* and remote sensors will be used to characterize the vertical structure of the atmosphere in the vicinity of an OB/OD release from the surface up to 2 to 3 km. Surface layer measurements include horizontal wind speed and direction, air temperature, relative humidity, net radiation, barometric pressure, precipitation, and turbulence. Vertical wind profiles are acquired by a 924 MHZ wind profiling radar and a phased-array Doppler sodar. A RASS is used to acquire profiles of virtual air temperature. A ceilometer has also been included to acquire information on aerosol backscatter and cloud base height. These ground-based remote sensors are mounted on a 7-m flatbed trailer which allows easy transport from one OB/OD facility to another. All of the computers used for data acquisition are networked together into a hub computer. The meteorological data are used by an OB/OD model residing on the primary system for predicting transport and dispersion of emissions released into the atmosphere.

5. ACKNOWLEDGMENTS

The authors wish to express thanks to William Mitchell for his support. Special thanks to David Gemmill and Alan Hoffman for their reviews and to Sherry Brown for developing the schematic. This work has been supported by the Strategic Environmental Research and Development Program project 251.

6. DISCLAIMER

This document has been reviewed in accordance with U. S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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